Accurate and precise effective temperature measurements of eclipsing binary stars

N. J. Miller[1], *P. F. L. Maxted*[1], *B. Smalley*[1]

[1]Astrophysics Group, Keele University, Staffordshire, UK

Abstract

Stars with accurate and precise effective temperature measurements are needed to test stellar atmosphere models and calibrate empirical temperature estimates, but there are **few such suitable standard stars**. Parallaxes from *Gaia* now make it possible to measure the fundamental effective temperature of many stars in detached (non-interacting) eclipsing binaries, and **establish a set of solar-type benchmark stars** with accurate and precise temperatures. We developed a new method for calculating the temperature of eclipsing binary stars that uses high precision photometry, parallax and multi-wavelength photometry. We applied it to a well studied system, AI Phoenicis (AI Phe), and obtained robust temperature measurements of **6199 ± 22 K** for the F7V component and **5094 ± 16 K** for the K0IV component.

Related publications

Miller N. J., Maxted P. F. L., Smalley B., 2020, MNRAS, 497, 2899

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Method

To measure the fundamental effective temperature, we need to know:

- **Radius** of the stars, emitting a
- **Total flux** in all wavelengths, measured at a
- **Distance** from the observer

Radius

This can be obtained by fitting light curves with eclipsing binary models. With *TESS* observations, the radii of some stars can be measured with **uncertainties smaller than 0.2%!**

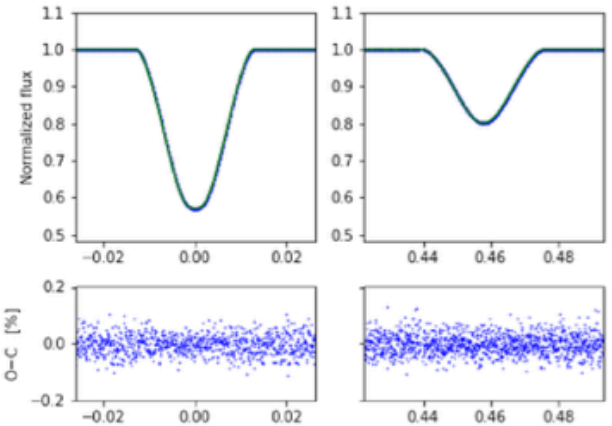
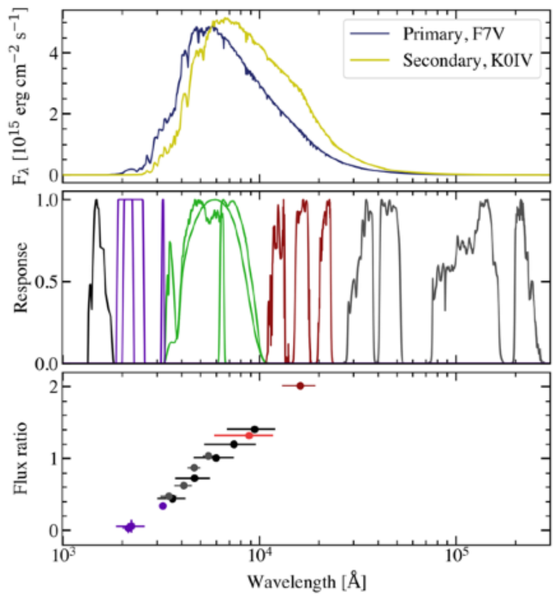


Figure: best fit to the light curve of AI Phe showing data (blue) and model (green) (Maxted et al., 2020)

Total flux

We aim to balance contributions from data and physics by creating a flux integrating function with realistic small-scale features (e.g. absorption lines) but a broad shape determined by observations.

This is done by using polynomials to distort model spectral energy distributions (top panel) for each star to "fit" multi-wavelength magnitude (middle panel), colour and flux ratio (bottom panel) observations, along with other data and constraints.



Distance

This is obtained from *Gaia* DR2 parallaxes.

Results

We applied our method to the well-studied eclipsing binary AI Phe:

- ☑ F7V + K0IV (ideal benchmark stars)
- ☑ Good quality light curves in several photometric bands from near-IR to near-UV
- ☑ Very accurate radii from Maxted et al. (2020)
- ☑ Strong upper limit on interstellar reddening

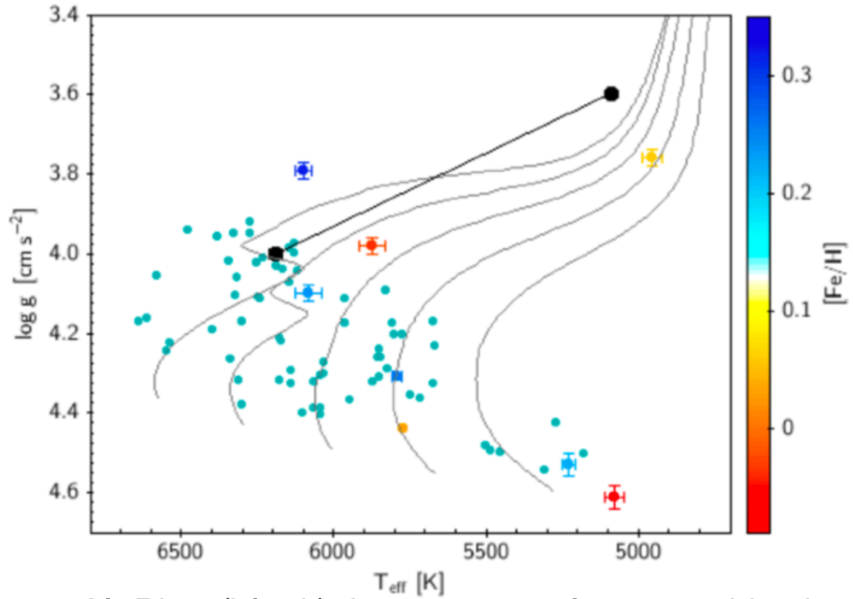


Figure: AI Phe (black) in context of stars with detailed asteroseismology in the Kepler LEGACY sample (cyan, Silva-Aiguirre+2017) & Gaia FGK benchmarks (Jofré+2018)

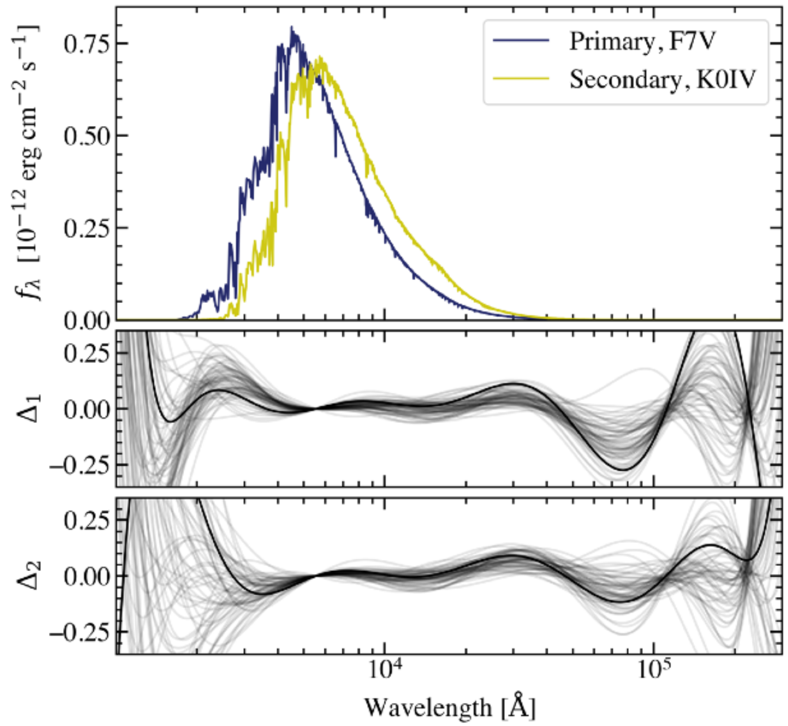


Figure: Output total flux distribution of the two stars in AI Phe (top) with the associated distortion functions for each star (lower panels).

We measured the effective temperatures as:

$T_1 = 6199 \pm 22$ K; $T_2 = 5094 \pm 16$ K

We tested all aspects of the method until we were satisfied our results were robust.

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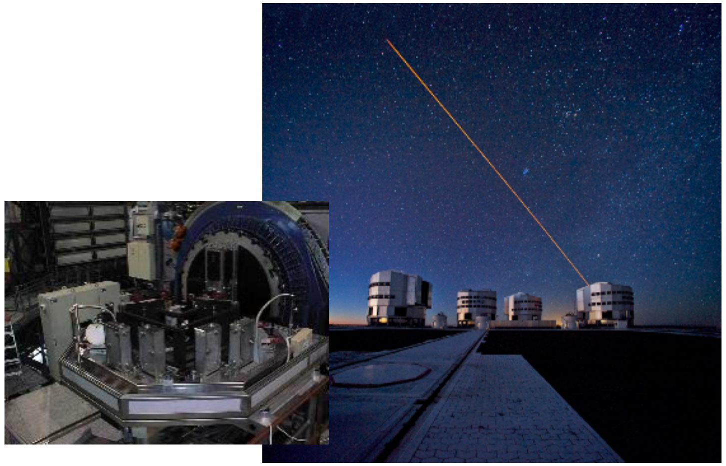
Next steps and prospects

More stars! We will continue applying the method to suitable eclipsing binary stars. There are already a handful of targets from *K2* fields but we expect many more to be observed by *TESS* over the next few years.



Follow up observations! We recently won observing time on the UVES instrument on the Very Large Telescope to follow up our work on AI Phe. By taking a spectrum during a total eclipse we can separate the spectra of the two stars for an independent determination of temperature and chemical composition.

Benchmarks! These results contribute to the *PLATO* Benchmark Stars work package, which aims to "measure precise and accurate fundamental properties of stars that can be used to validate and improve data products from the *PLATO* mission". *PLATO* is an upcoming ESA mission which will search for Earth-like planets in the habitable zone around solar-type stars.